

**AMENDMENTS TO THE SPECIFICATION:**

**Please replace the paragraph beginning on page 1 with the following amended paragraph:**

The present invention relates to improvement of a motor, which is most suitable for use in an electric power steering ~~device~~ apparatus, and a drive control device for the motor as well as an electric power steering ~~device~~ apparatus using the motor and the drive control device.

**Please replace the paragraph 2 beginning on page 1 with the following amended paragraph:**

Conventionally, a motor used in an electric power steering ~~device~~ apparatus is, in general, a permanent magnet synchronous motor (PMSM), which is driven by a three-phase sinusoidal current. As a control system for driving the motor, a control system called vector control is widely used. However, since there is a strong demand for a reduction in size of the electric power steering ~~device~~ apparatus, a brushless DC motor tends to be used as a motor suitable for the reduction in size.

**Please replace paragraph 3 beginning on page 1 with the following amended paragraph:**

Under such circumstances, a motor drive control device using the ~~vector-advance angle~~ control system for the conventional motor for the electric power steering ~~device~~ apparatus will be explained with reference to Fig. 1.

**Please replace paragraph 4 beginning on page 1 and bridging page 2 with the following amended paragraph:**

In a structure of the motor drive control device, a main path leading to the motor 1 is connected to the back of a current command value calculating unit 100 that controls an electric current of a motor 1 via subtracters 20-1, 20-2, and 20-3 that detect errors between phase current command values  $I_{avref}$ ,  $I_{bvref}$ , and  $I_{cvref}$  and motor currents  $I_a$ ,  $I_b$ , and  $I_c$ , a PI control unit 21 that inputs respective error signals from the subtracters 20-1, 20-2, and 20-3, a PWM control unit 30 that inputs voltages  $v_a$ ,  $v_b$ , and  $v_c$  from the PI control unit 21, and an inverter 31 that converts

a direct current into an alternating current. Current detecting circuits 32-1, 32-2, and 32-3, which detect the motor currents Ia, Ib, and Ic, are arranged between the inverter 31 and the motor 1. A feedback control system B, in which the detected motor currents Ia, Ib, and Ic are fed back to the subtracters 20-1, 20-2, and 20-3, respectively, is formed.

**Please replace paragraph 5 beginning on page 2 and bridging page 3 with the following amended paragraph:**

Next, the current command value calculating unit 100 will be explained. First, concerning inputs thereof, a torque command value Tref calculated from a torque detected by a not-shown torque sensor, a rotation angle  $\theta_e$  of a rotor in the motor 1 detected by a position detecting sensor 11 connected to the motor 1, and an electrical angular velocity  $\omega_e$  calculated by a differentiating circuit 24 are inputted. A converting unit 101 calculates counter-electromotive forces ea, eb, and ec with the electrical angular velocity  $\omega_e$  and the rotation angle  $\theta_e$  of the rotor as inputs. Next, a three-phase/two-phase converting unit 102 converts the counter-electromotive forces ea, eb, and ec into a d-axis component voltage ed and a q-axis component voltage eq. A q-axis command current calculating unit 108 calculates a current command value on a q-axis Iqref with the d-axis component voltage ed and the q-axis component voltage eq as inputs. However, in this case, a current command value on a d-axis Idref is calculated as 0. In other words, in the following output equation of a motor,

$$T_{ref} \times \omega_m = 3/2(ed \times I_d + eq \times I_q) \quad (1)$$

when  $I_d = I_{dref} = 0$  is inputted, the equation is calculated as follows.

$$I_q = I_{qref} = 2/3(T_{ref} \times \omega_m / eq) \quad (2)$$

~~Current-Phase~~ current command values Iavref, Ibvref, and Icvref are calculated on the basis of a current command value Iqref from the q-axis command current calculating unit 108 and an advance angle  $\Phi$  of advance angle control described later. In other words, a two-phase/three-phase converting unit 109 calculates the phase current command values Iavref, Ibvref, and Icvref based on the advance angle  $\Phi$  calculated in the advance angle calculating unit 107 and the current command value Iqref calculated in the q-axis command current calculating unit 108~~inputs the~~

~~advance angle  $\Phi$  and the current command value  $I_{qref}$  calculated by an advance angle calculating unit 107 and a two phase/three phase converting unit 109 calculates the current command values  $I_{avref}$ ,  $I_{bvref}$ , and  $I_{cvref}$ .~~

**Please replace paragraph 9 beginning on page 4 with the following amended paragraph:**

While the motor 1 is not rotating at high speed, that is, while a mechanical angular velocity  $\omega_m$  of the motor 1 is lower than the motor base angular velocity  $\omega_b$ , it is possible to output a torque complying with the torque command value  $T_{ref}$  if the phase current command values  $I_{avref}$ ,  $I_{bvref}$ , and  $I_{cvref}$  in accordance with a value calculated from the current command value  $I_{qref}$  by the two-phase/three-phase converting unit 109 regardless of the advance angle  $\Phi$ . This means that, as the electric power steering device, wheel operation by a driver is executed smoothly.

**Please replace paragraph 10 beginning on page 4 with the following amended paragraph:**

However, when the motor 1 rotates at high speed, that is, the mechanical angular velocity  $\omega_m$  of the motor is higher than the motor base angular velocity  $\omega_b$ , an angular velocity higher than the base angular velocity  $\omega_b$  cannot be realized unless control taking into account the advance angle  $\Phi$  is executed. When this high-speed rotation of the motor 1 is considered from a viewpoint of the electric power steering ~~device~~apparatus, in the case of sudden steering of a wheel for turn in parking a car or emergency shelter, steering feeling of the driver is deteriorated because the motor 1 does not follow the wheel operation.

**Please replace paragraph 12 beginning on page 5 with the following amended paragraph:**

As a motor drive control system used in the electric power steering ~~device~~apparatus, vector control, which is adapted to generate a rotating magnetic field from a control device via an inverter on the basis of rotating position of a rotor to control to drive rotation of the rotor, is adopted. In other words, the vector control is adapted to, in plural exciting coils arranged at

intervals of a predetermined angle on an outer peripheral surface of the rotor, control rotation drive for the rotor by sequentially switching excitation of the respective exciting coils using a control circuit according to a rotor position.

**Please replace paragraph 18 beginning on page 8 and bridging page 9 with the following amended paragraph:**

Incidentally, the d-axis component and the q-axis component generated by the advance angle control simply advance the current command value  $I_{qref}$  by the phase  $\Phi$ . Thus,  $I_{qref} \times \sin\Phi$  on the d-axis and  $I_{qref} \times \cos\Phi$  on the q-axis are restricted to a fixed relation and a quantitative balance is not always optimized. As a result, a motor terminal voltage is saturated at the time of high-speed rotation and a motor current cannot follow a current command value, whereby torque ripple increases and motor noise also increases. Therefore, as the electric power steering ~~device~~apparatus, inconveniences are caused in that, for example, a driver feels abnormal vibration through a wheel at the time of rapid wheel steering and motor noise is caused to give unpleasant feeling to the driver.

**Please replace paragraph 22 beginning on page 11 with the following amended paragraph:**

Therefore, according to the conventional motor control, there is a problem in that torque ripple is large and noise of the motor is also large. When such motor control is applied to the electric power steering ~~device~~apparatus, the electric power steering ~~device~~apparatus cannot assist steering accurately and smoothly following wheel operation. Thus, there is a problem in that a driver feels vibration at the time of steering and noise increases.

**Please replace paragraph 23 beginning on page 11 with the following amended paragraph:**

The invention has been devised because of the circumstances described above and it is an object of the invention to provide a motor and a drive control device for the motor, in which torque ripple is reduced and noise is reduced by controlling nonlinear elements included in motor control in a state in which the nonlinear elements are separated into respective phases, and also

provides an electric power steering ~~device-apparatus~~ that adopts the motor and the drive control device to have an improved steering performance and satisfactory steering feeling.

**Please replace paragraph 24 beginning on page 11 and bridging page 12 with the following amended paragraph:**

It is another object of the invention to provide a motor drive control device, in which a motor terminal voltage is not saturated even at the time of high-speed rotation of a motor, torque ripple is reduced and motor noise is reduced, and an electric power steering ~~device-apparatus~~ in which noise is reduced at the time of rapid steering of a wheel and with which wheel operation can follow the steering smoothly.

**Please replace paragraph 27 beginning on page 12 and bridging page 13 with the following amended paragraph:**

The invention relates to a motor drive control device that controls a motor having three or more phases. The motor drive control device has a vector control phase current command value calculating unit that calculates phase current command values of the respective phases of the motor using vector control, a motor current detecting circuit that detects motor phase currents of the respective phases of the motor, and a current control unit that controls phase currents of the motor on the basis of the phase current command values and the motor phase currents, whereby the object of the invention is attained. In addition, the vector control phase current command value calculating unit has a counter-electromotive force of each phase calculating unit that calculates a counter-electromotive force of each phase, a d-q voltage calculating unit that calculates voltages  $e_d$  and  $e_q$ , which are d-axis and q-axis components of a counter-electromotive force, from the counter-electromotive force of each phase, a q-axis command current calculating unit that calculates a current command value  $I_{qref}$ , which is a q-axis component of a current command value, from the voltages  $e_d$  and  $e_q$ , a d-axis command current calculating unit that calculates a current command value  $I_{dref}$  that is a d-axis component of a current command value, and an each-phase current command calculating unit that calculates phase current command values of the respective phases from the current command values  $I_{qref}$  and  $I_{dref}$ , whereby the object of the invention is attained. Further, when the motor has three

phases, phase current command values  $I_{avref}$ ,  $I_{bvref}$ , and  $I_{cvref}$  are calculated according to a constant depending on the current command values  $I_{dref}$  and  $I_{qref}$  and a rotation angle  $\theta_e$  of the motor, whereby the object of the invention is attained.

**Please replace paragraph 28 beginning on page 14 with the following amended paragraph:**

The current control circuit includes integral control, the motor is a brushless DC motor, a current of the motor is a rectangular wave or a pseudo-rectangular wave, or the motor drive control device is used in an electric power steering ~~device~~apparatus, whereby the object of the invention is attained more effectively.

**Please replace paragraph 54 beginning on page 22 with the following amended paragraph:**

In the invention, a motor drive control device shown in Fig. 8 is formed for the motor (with the number of poles  $P$ ) having such characteristics. The motor drive control device of the invention includes a vector control phase current command value calculating unit 20, subtracting circuits 20-1, 20-2, and 20-3 that calculates respective phase current errors on the basis of phase current command values  $I_{avref}$ ,  $I_{bvref}$ , and  $I_{cvref}$  from the vector control phase current instruction value calculating unit 20 and motor phase currents  $I_a$ ,  $I_b$ , and  $I_c$  from current detecting circuits 32-1, 32-2, and 32-3, and a PI control unit 21 that performs proportional integral control. Respective phase command currents are supplied from an inverter 31 to the motor 1 according to PWM control of the PWM control unit 30 to control rotation drive for the motor 1. An area A indicated by a broken line forms a current control unit.

**Please replace paragraph 55 beginning on page 22 and bridging page 23 with the following amended paragraph:**

In this embodiment, in the vector control phase current command value calculating ~~circuit-unit~~ unit 20, current command values of vector control  $d$  and  $q$  components are determined using an excellent characteristic of vector control and, then, the current command values are converted into respective phase current command value. The vector control phase command

value calculating circuit 20 is closed with phase control rather than d and q control in a feedback control unit. Thus, since the theory of vector control is used at a stage of calculating a current command value, this control system is called pseudo-vector control (hereinafter referred to as "PVC control").

**Please replace paragraph 65 beginning on page 27 and bridging page 28 with the following amended paragraph:**

However, the current command value  $I_{dref}$  represented by expression (67) has a negative polarity and an induced voltage component of the current command value  $I_{dref}$  concerning  $L(di/dt)$  of expression (67) has a polarity opposite to that of the counter-electromotive force  $E$ . Thus, there is an effect that the counter-electromotive force  $E$ , which increases as the motor rotates at higher speed, is reduced by a voltage induced by the current command value  $I_{dref}$ . As a result, even if the motor 1 rotates at high speed, the range of a voltage, which can control the motor, is increased by the effect of the current command value  $I_{dref}$ . In other words, there is an effect that a control voltage for the motor is not saturated by the field-weakening control according to the control for the current command value  $I_{dref}$ , the range of a voltage, which can control the motor, is increased, and torque ripple is prevented from increasing even at the time when the motor rotates at high speed.

**Please replace paragraph 71 beginning on page 31 with the following amended paragraph:**

The current command values  $I_{dref}$  and  $I_{qref}$  are inputted to the two-phase/three-phase converting unit 104 serving as the each-phase current command value calculating unit and converted into the phase current command values  $I_{avref}$ ,  $I_{bvref}$ , and  $I_{cvref}$  of the respective phases. The current command values  $I_{dref}$  and  $I_{qref}$  and the phase current command values  $I_{avref}$ ,  $I_{bvref}$ , and  $I_{cvref}$  are represented like expressions (12) and (13). Here, a subscript, for example, "avref" of the phase current command value  $I_{avref}$  represents a phase current command value of an a-phase determined by the vector control. Note that, as indicated by expression (13), a determinant  $C2$  is a constant that is determined by the motor rotating angle  $\theta_e$ .

**Please replace paragraph 72 beginning on page 32 with the following amended paragraph:**

Conventionally, the two-phase/three-phase converting unit 109 in Fig. 1 calculates the phase current command values  $I_{avref}$ ,  $I_{bvref}$ , and  $I_{cvref}$  using the current command value  $I_{qref}$  and the advance angle  $\Phi$ . In the invention, as described above, the two-phase/three-phase converting unit 104 calculates the phase current command values  $I_{avref}$ ,  $I_{bvref}$ , and  $I_{cvref}$  with the current command values  $I_{dref}$  and  $I_{qref}$  as inputs. Then, the subtracting circuit 20-1, 20-2, and 20-3 subjects the respective phase currents  $I_a$ ,  $I_b$ , and  $I_c$  of the motor detected by the current detecting circuits 32-1, 32-2, and 32-3 and the phase current command values  $I_{avref}$ ,  $I_{bvref}$ , and  $I_{cvref}$  to calculate respective errors. Next, the PI control unit 21 controls the errors of the respective phase currents to calculate a command value for the inverter 31, that is, the voltage values  $v_a$ ,  $v_b$ , and  $v_c$  representing duty of the PWM control unit 30. The PWM control unit 30 subjects the inverter 31 to the PWM control on the basis of the voltage values  $v_a$ ,  $v_b$ , and  $v_c$ , whereby the motor 1 is driven and a desired torque is generated.

**Please replace paragraph 80 beginning on page 35 with the following amended paragraph:**

According to the invention, a motor terminal voltage is not saturated even at the time when a motor is rotating at high speed, torque ripple is reduced, and motor noise is reduced. Thus, if the invention is applied to an electric power steering ~~device~~apparatus, it is possible to provide an electric power steering ~~device~~apparatus that follows rapid steering of a wheel smoothly, does not cause a sense of incongruity in wheel operation, and has reduced noise.

**Please replace paragraph 81 beginning on page 35 and bridging page 36 with the following amended paragraph:**

According to the electric power steering ~~device~~apparatus in the invention, respective phase current instruction values are calculated on the basis of the vector control, and the PVC control for controlling respective phases separately is used as current feedback control. Thus, it is possible to provide a motor drive control device that can control the brushless DC motor to be



small, have reduced torque ripple, and have reduced motor noise. It is possible to provide an electric power steering system with which wheel operation is smooth and noise is reduced.

**Please delete the present Abstract of the Disclosure, and add the following new Abstract of the Disclosure:**

The invention provides a motor for a brushless DC motor, which has small torque ripple even if a trapezoidal wave current is supplied and has a small size and reduced motor noise, and a drive control device for the motor as well as an electric power steering apparatus using the motor and the drive control device. Respective phase current command values are calculated on the basis of vector control. Pseudo-vector control for controlling respective phases separately is used as current feedback control.